An All Sky Cirrus Confusion Noise Map for WIRE

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1. WIRE Requirements

The Wide Field Infrared Explorer (WIRE) is an infrared space observatory being developed under NASA's small explorer program for launch in late 1998 (Schember, et al, 1996). WIRE's main function will be to produce a sky survey at wavelengths of 12 and 25 μm covering several tens of square degrees at a sensitivity of 0.2 mJy, 5σ at 25 μm, and several hundred square degrees at a sensitivity of 0.7 mJy, 5σ at 25 μm to study starburst galaxies and search for luminous protogalaxies. The exact sensitivity requirements depend on the, as yet unknown, evolutionary history of very distant galaxies. The numbers above represent the worst case for sensitivity requirements, that is no evolution. WIRE will use a 30 cm telescope and 128x128 Si:As array detectors with 0.5°x0.5° fields of view to produce the survey.

The high sensitivity levels needed for WIRE science cannot be achieved every where over the sky due to background confusion from galactic sources. WIRE need not attempt survey observations at low galactic latitudes where many sources of intense emission contribute to the background confusion. At higher latitudes where WIRE must operate, background confusion from dust emission, the infrared cirrus, remains and must be evaluated to provide a criterion for selection of suitable WIRE survey areas. WIRE science requires confusion noise levels below 10% of the 5σ sensitivity levels at 25 μm: < 23 mJy, 1σ for the deep survey and < 115 mJy, 1σ for the moderate survey.

2. Method

Gautier, et al. (1992) presented a method for predicting noise in point source flux measurements due to background fluctuations which uses the spatial power spectral distribution (PSD) of the background. Given a particular geometry and scale of signal and background apertures on the sky, the expected fluctuation in [$source\ flux = (signal + background) - background$] can be related to the PSD of the background. For power law PSDs ($PSD = P_0\, \mathrm{d}^{-\alpha}$, see below) the rms fluctuation is

$$\mathrm{rms} = \sqrt{PSD(\mathrm{d}_0)}\, E_0\, (\mathrm{d}/\mathrm{d}_0)^{(1-\alpha/2)} \qquad (1)$$

where α is the power law index of the PSD, d is the scale of the aperture geometry, d_0 is a normalizing scale and E_0 is a constant associated with d_0 and the geometry of the apertures. This technique can be used to predict the confusion noise contribution to WIRE measurements if the PSD of the 25 μm cirrus emission can be determined at the spatial scales relevant to WIRE. The IRAS ISSA all sky map data provides a basis for measurement of cirrus PSD over large regions of the sky.

Gautier, et al. (1992) and Abergel, et al. (1996) have measured the PSD of infrared cirrus emission seen in the IRAS data at 12, 25, 60 and 100 μm and have found it to be well represented by a power law. Cutri (Low and Cutri, 1994) has performed a similar analysis on the visible red light from reflection nebulae associated IRAS cirrus clouds and also found power law PSDs with indices essentially equal to those seen in the infrared. These observations suggest that it is reasonable to predict the PSD of 25 μm cirrus at WIRE spatial scales by measuring the PSD of cirrus at 100 μm on spatial scales accessible in the IRAS data, extrapolating to WIRE scales and correcting with the observed $25\mu m/100\mu m$ flux ratios. IRAS ISSA data supplies PSD information at scales near 1°. Extrapolation by a factor of about 120 is needed to reach the WIRE point source extractor scale. Data and arguments presented in the next section indicate that the uncertainty in the WIRE noise prediction is about a factor of 2 for this extrapolation. Fluctuations in the $25\mu m/100\mu m$ flux ratio on the order of a factor 3 may occur. These factors should result in an uncertainty of about a factor of 4 in the WIRE noise prediction; useable for survey planning. Monitoring of the $25\mu m/100\mu m$ flux ratio, at least at lower galactic latitudes where the 25 μm flux is available, can improve this uncertainty.

The Fourier transform method for determination of sky background PSDs used by Gautier, et al. (1992) dots not lend itself to good spatial resolution in determination of the PSD because the Fourier transform smears spatial information at all sclaes over the whole transform space. The WIRE survey planning needs spatial resolution on the degree scale for its cirrus noise predictor. Wavelet transforms usc basis functions of finite extent and offer a method for obtaining spatially resolved PSD information (Farge 1992). The noise predictor described here uses a Burt pyramid wavelet transform technique which convolves images with a series of low pass filters and combines the results to effectively produce ISSA maps filtered with a series of constant Q band pass filters spaced every octave. The wavelet filter pass bands were calibrated for gain and effective scale using synthetic maps with known power law *1',$1)s.* The mean square value, averaged over an area several times the size of the wavelet kernel, of a calibrated, filtered image effectively reproduces the Fourier transform power law' spectrum sampled every octave and allows good determination of the index and value of the PSD. Higher spatial resolution than the 12.5°x12.5° of the ISSA map is obtained by averaging the wavelet filtered images over smaller blocks of the image. A conceptually similar method was used by Abergel, et al. (1996).

3. Results

Wavelet PSD analysis has been used to predict the cirrus confusion noise for WIRE in eight 12.5°x12.5° ISSA fields with galactic latitude ranging from 11° to 50° (Table 1). The ISSA 100 μm maps were first cleaned of bright compact sources, filled out to 512x512 pixels by removing the average value of the map and tapering the edge to zero over six pixels and given a mild treble boost the remove most of the ISSA transfer function as determined from an average of

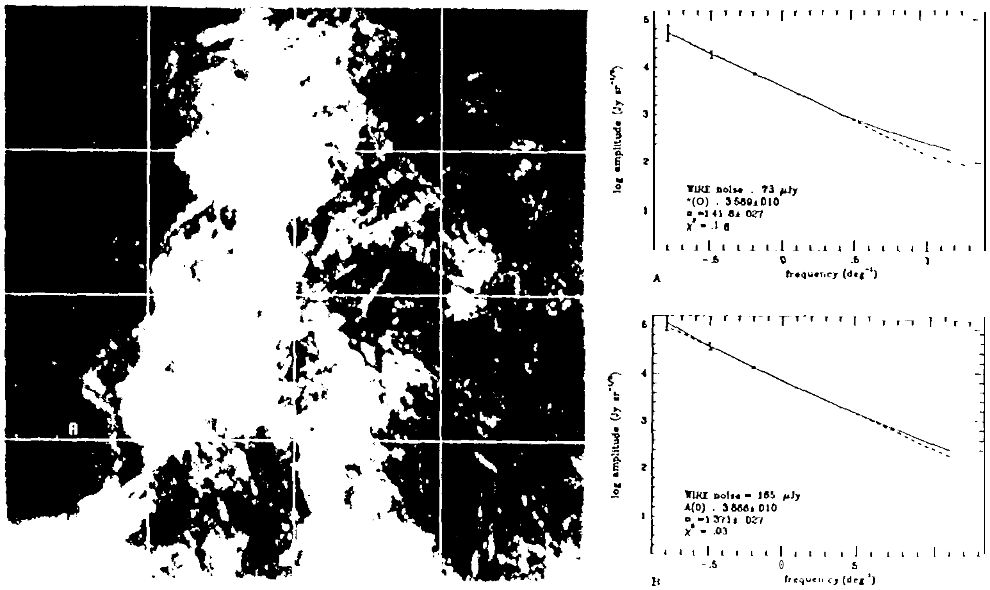

Figure 1. Left) ISSA field *430*, after removal of point sources and anodization. The grid divides the image into the averaging regions for the wavelet PSD spectra. Right) Wavelet PSD spectra for the two grid arms indicated. The calculated values of χ^2 arc suspect since they include only formal uncertainty estimates of the wavelet filter process and not any estimate of variation of the real cirrus structure distribution.

point spread functions found in the ISSA maps. Next a double density Burt pyramid wavelet transform using a separable 5x5 filter kernel was applied to produce seven output maps corresponding to scales from about 3' to 3°. The rms value of the transform maps was produced by averaging over sixteen 3"x3" blocks corresponding to 128x128 pixels of the original map. This averaging is sufficiently large to be useful for all but the largest scale transform map where only sixteen output pixels are ave.raged. Figure 1 shows the wavelet PSD spectra and predicted WIRE noise in this 4x4 grid of 3°x30 arms for two ISSA fields. The power law fit excluded the largest scale and the two smallest scales. As explained above, the largest scale was excluded because of insufficient averaging, the smallest two scales are adversely affected by the treble boost function derived from the ISSA point sources.

The WIRE flux extractor is assumed to have an annular geometry with a source aperture of $29.6''$ diameter surrounded by a background ring of $29.6''$ width. The 100 μm/25 μm brightness ratio for cirrus was assumed to be 15.54 30% for conversion from 100 μm PSD to 25 μm PSD value (Gautier and Stewart, 1994 and Boulanger and Perault, 1988).

The expected uncertainty of the WIRE noise prediction has been estimated from the calibration of the wavelet pass band filters and the quality of the fit of the observed PSD to a power law. The 10 error bars shown in Figure 1 are derived from the distribution of wavelet power obtained from analysis of synthetic

Table 1. Regions analyzed.

Area	ISSA Field	R.A.	Dec.	l	b
Chamaeleon	006	12h 00m	-80	300.8	-17.6
Taurus	276	4h 12m	+20	174.6	-21.7
Taurus	277	4h 54m	+20	181.2	-14.1
Taurus	311	4h 36m	+30	170.6	-11.0
Ursa Major	413	8h 40m	+70	139.0	+42.6
Ursa Major	414	10h 24m	+70	139.0	+42.6
North Polar Cloud	430	0h 00m	+90	123.0	+27.4
HI hole	-	10h 27m	+58	151.8	+50.5

images with well defined power law spectra. Additions to the uncertainty from statistically expected departures of the cirrus structure from an exact power law have not yet been made. A preliminary estimate of the uncertainty added by the natural cirrus indicates that the error for the small scale wavelet power should be that of the point at log $f = -0.2$. Then the 1σ uncertainty on α increases to $\simeq 0.043$. This results in a 3σ factor of $120^{(.129)} = 1.85$ uncertainty, from this source, in the predicted WIRE noise. The estimate of a factor of 2 uncertainty in the WIRE noise due to *PSD* estimation given above seems reasonable.

4. Current Work

We are in the process of extending the WIRE noise predictions to all of the sky above about $|b| > 10$ and increasing the spatial resolution to $< 2°$. The ultimate goal is to produce an all sky ($|b| > 10$) noise prediction map for use with the WIRE survey scheduling tool. The next need is to understand how much the useable deep and moderate survey sky exceeds our previous expectations and what effect this will have on WIRE observing efficiency. We are also investigating the efficiency of other confusion noise predictors, such as the shape of image histograms, which can be derived from, the ISSA data more easily than the PSD function. Other such predictors would be calibrated with the PSD method.

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